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LIFE CYCLE COST ANALYSIS MODEL. PART I. THE MATHEMATICAL MODEL.(U)

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LIFE CYCLE COST ANALYSIS MODEL

PART I

THE MATHEMATICAL MODEL

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By

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Night Vision & Electro-Optics Laboratory

MARCH 1979

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PART I of this report describes the development of a mathematical model for the life cycle cost analysis of electronics, electro-optical, optical, and opto-mechanical systems. PART II is a user/operator manual for the associated computer program. PART III describes the computer program itself as written in FORTRAN for the CDC 6600 computer system.

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NIGHT VISION & ELECTRO-OPTICS LABORATORY LIFE CYCLE COST ANALYSIS MODEL

PART I

THE MATHEMATICAL MODEL

BY

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MARCH 1979

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TABLE OF CONTENTS

		Page
1.	INTRODUCTION	1
1.1	Purpose	1
1.2	Background	1
1.3	Summary	4
2.	THE BASIC MATHEMATICAL MODEL - GENERAL METHODOLOGY	6
2.1	Basic Model Formalism	6
2.2	Basic Assumptions	6
2.3	Basic Input Parameters, Schedules, and Constants	8
2.4	Program Algorithms	10
2.5	Model Equations	12
3.	SPECIAL CONSIDERATIONS AND METHODOLOGY	24
3.1	General	24
3.2	Tank Thermal Sight, TTS (AN/VSG-2) Application Problem Description	24
3.3	Remote Piloted Vehicle, RPV Application	26
3.4	Light Emitting Diode Array (LED) Product Improvement Application	30
4.	INPUT DATA REQUIREMENTS	33
4.1	General	33
4.2	Initial Data Requirements	33
5.	UNCERTAINTY AND SENSITIVITY	36
5.1	General	36
5.2	Uncertainty	36
5.3	Sensitivity	37
6.	EXERCISING THE MODEL	38
6.1	Manual Processing	38
6.2	Computer Processing	38

1. INTRODUCTION

1.1 PURPOSE

The purpose of this report is to describe a Life Cycle Cost Mathematical Model which has been developed at the Night Vision and Electro-Optics Laboratory at Fort Belvoir, Virginia, and to provide potential users of the model with sufficient information and guidance to adapt this model to the analysis of systems within the user's field of interest. PART I of this report will describe the basic mathematical model and its development. PART II is a user's manual describing the use of the associated computer program, and PART III is a detailed description and listing of the computer program itself.

1.2 BACKGROUND

The developmental history of the Night Vision and Electro-Optics Laboratory Life Cycle Cost Model dates back to 1970 when the Laboratory's management recognized the need for an in-house capability in cost analysis as an aid to the effective management of programs growing in cost and complexity. By 1972 life cycle cost and risk analysis was being performed by Sirota, Shields, Swenson, Kramer, et. al. at the Laboratory on a variety of electro-optical systems. In June of 1973 Sirota, Shields and Kramer developed the nucleus of the Night Vision System Life Cycle Cost Model and Computer Program.[1] This basic model was validated by personnel of the Comptroller's office at Headquarters ECOM at Fort Monmouth, New Jersey, and presented at an IRIS meeting that year by F. Shields. It was subsequently adopted by the Project Manager REMBASS and continues in use in that program as the REMCOS Computer Program.[2] Its initial use at the then Night Vision Laboratory was in the Phase I Engineering Development Source Selection Evaluation for the TOW Night Vision System.

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1. Shields, F., D. Sirota, and S. Kramer, Life Cycle Cost Analysis, IRIS Proceedings, Jun 1973.
2. ECOMP 11-4, Volume 7, PX-16.

In 1975 the model and computer program were revised by Sirota, Morrow and Sijgers[3] to create a substantially more flexible and useful tool for the Phase II ED Source Selection Evaluation for the TOW Night Vision System, and the AN/TAS-6 Night Observation Device, Long Range (NODLR).[4] Prior to actual use of the revised model and program, several briefings were held to obtain constructive criticism and comment and to confirm the soundness of the methodology employed. The first briefing was given to personnel of the Cost Methodology Section, Cost Analysis Division of the Headquarters ECOM Comptroller's Office; the second to personnel of the Logistics Evaluation Agency at the New Cumberland Army Depot; and the final briefing was given to a combined audience of personnel representing the USAMICOM Comptroller's Office, PM TOW, PM DRAGON, and PM GLLD/LTD. A respectable number of the suggestions and recommendations made by members of this audience of users and validators were subsequently incorporated into the model benefiting all concerned. Additional minor modifications extended its usefulness and in 1976 it was the basic cost analysis tool for the AN/VSG-2 Tank Thermal Sight Source Selection Evaluation.[5, 6]

Subsequent utilization of the model has been expanded to include the AN/TAS-5 Night Vision System for DRAGON, various infrared viewing systems for airborne and combat vehicle application, image intensifier Night Vision Systems and components,[7] laser range finders and target designators, and

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3. Sijgers, H., User Manual, Life Cycle Cost Analysis Program for Night Vision Systems, Systematics General Corp., Sep 1975.
4. Manportable Common Thermal Night Sight Evaluation, Findings and Recommendations of the Source Selection Evaluation Board, USADARCOM, 24 Sep 1975.
5. Sirota, D. B., Life Cycle Cost Analysis, Tank Thermal Sight AN/VSG-2( ), NV&EOL Rept, Nov 1975.
6. Sirota, D, Morrow, W., Garcia, J., and Bugbee, G., Cost Group Report, Tank Thermal Sight Evaluation, May 1976.
7. Sirota, D., Morrow, W., and Franseen, R., Life Cycle Cost Study for Night Vision Goggle Tube Assemblies, NV&EOL Rept., 28 Feb 1978.

television security systems,[8] etc. Beyond Night Vision Electro-Optical Systems per se, the model has proven its value in the analysis of various ancillary equipments used in support of Night Vision Systems. These include battery chargers, stations for cleaning and charging high pressure gas bottles such as the AN/TAM-4, mobile field maintenance facilities such as the AN/TAM-3 and their attendant trucks, trailers, electric generators and air conditioners.

In 1978 another set of modifications was undertaken by Sirota, Morrow and Skelton to deal with problems arising from the various cost exercises associated with the annual federal budget cycle. These and other additions relating to the preparation of Independent Government Cost Estimates IGCE's for the procurement process are discussed in this report.

At the present time the model and computer program can be applied to a wide variety of electronic, electro-optical, optical, and mechanical systems. It can take account of detailed modular structure and wide spread component or modular commonality. Given a procurement and delivery schedule, future systems costs can be computed. Conversely, given budget constraints in future years a procurement schedule can be derived. It is possible also to mix system schedule/quantity and budget constraints while iterating the program model. In this last mode the model is used almost continuously by NV&EOL Management as a program planning and budgeting tool in support of the TOW/DRAGON Project Office. In this application there is a complex interaction of systems (AN/TAS-4, AN/TAS-5, and AN/TAS-6), support equipment (AN/TAM-3, and AN/TAM-4), prime and second source system contractors, third source module contractors and subsystem contracts being awarded and managed by two Commands MIRCOM and ERADCOM (NV&EOL), as well as differentiated Army and Marine Corps requirements.

8. Swenson, J.M., Remote Surveillance Monitor Cost Study, USAF Project BIS, NV&EOL Rept., Apr 1978.

1.3 SUMMARY

A computerized Life Cycle Cost Analysis Model has been developed at NV&EOL which is applicable to a wide range of systems within the DARCOM Community. The model has been developed with attention to the specific data requirements in the DoD planning, programming, and budgeting cycles. Changing budgets and/or procurement/deployment schedules can be handled on a timely basis with the model to provide the user with a valuable management tool covering near and far term cost projections over the full economic life of the systems being analyzed. Moreover, the computer model is well structured to handle the recurring analyses characteristic of zero base budgeting.

The current Life Cycle Cost Model has evolved as a result of NV&EOL's common module program. The use of the same module in different systems has substantial life cycle cost implications. In order to handle this problem, it has been necessary to develop a model which describes a number of systems at once as well as the cost coupling due to application of common modules. The primary effect of commonality is to reduce the per unit cost of each module. In addition, there are minor effects due to shared nonrecurring facilitization and tooling, maintenance facilities, and training.

Rather than depending on a few simple parameters as with some commercially available Life Cycle Cost Models (e.g., the RCA PRICE model), the NV&EOL model uses the best available information for all input data. While the parametric models minimize input requirements, it is believed that the NV&EOL approach is more appropriate to the DoD procurement and long range planning environment.

The NV&EOL Life Cycle Cost Model is a dynamic model which is continually evolving as new requirements are imposed. Present plans call for the model to

be expanded to provide for industrial engineering data inputs, such as labor, materials, overhead, G&A and profit, as primary inputs to the model. Also planned for the near future, are time variable module parameters which would allow for a more accurate evaluation of product improvement costs.

As with any system model, the results are only as good as the data input. In the case of life cycle cost models, accurate data is often very difficult to obtain and results for isolated systems are very uncertain. The model is most useful in comparing relative life cycle costs of several competing system alternatives. The difference between systems is much more significant in a statistical sense.

While no model can handle every situation, a great deal of flexibility has been built into the NV&EOL model.

2.0 BASIC MATHEMATICAL MODEL - GENERAL METHODOLOGY

2.1 BASIC MODEL FORMALISM

The model is based on the Rand Corporation's life cycle cost estimating methodology, which determines the costs for a system's development, investment, and operating phases.[9] Development phase costs can be subdivided into engineering, prototype fabrication, test and evaluation, data, training, systems management, and producibility study.

Investment phase costs can be subdivided into documentation, initial production facilities, training, hardware, provisioning, maintenance float, initial transportation, quality assurance, production engineering, engineering change orders, testing, and systems management. Costs for the operating phase can be subdivided into personnel, consumption, nonstandard line items, inventory holding, depot maintenance, transportation, and depot overhaul. The foregoing lists are merely indicative of the types of cost parameters which may be included in each phase and are by no means exhaustive.

2.2 BASIC ASSUMPTIONS

The model is based on a modular, or subassembly, maintenance concept. Field maintenance consists of troubleshooting the malfunctioning basic system to isolate and replace defective modules and subassemblies. Field maintenance will be performed at the direct support/general support (DS/GS) locations.

Defective modules and subassemblies are then shipped to the depot for repair. The model contains optional routines for a modular and system maintenance float to allow for 100 percent system availability. In the model the use rate per system in the field, and its MTBF (reciprocal failure rate) determine the number of systems required to fill the maintenance pipeline at the systems level. At the module level the LCC model computes module floats directly

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9. Massey, H.G., et al, Cost Measurement - Tools and Methodology for Cost Effectiveness Analysis, Rand Corp., Feb 1972.

from the system use rate, the module MTBF, and the turn around time for depot repair. This type of calculation deals directly with the realities of modular design and maintenance logistics. The deployment concept assumed is in accordance with Basis of Issue Plan (BOIP) for the individual systems involved. Delivered units are deployed concurrently with delivery or are stored in the depot as combat consumption units for a time period equal to the defined economic life of the system. Deployed systems are assumed to be attrited at a rate of 1 percent per year except for large items such as trucks, vans, etc. This has been a typical historical attrition rate for ECOM supported equipment. Any appropriate value may be used in the model. Attrited units are replaced by concurrent deployment of depot-stored combat consumption units in order to maintain a constant level of deployment. An alternative approach, which has been under consideration but not used thus far, is to assume reprocurement at a rate sufficient to offset attrition and maintain a constant deployment level until the end of the economic life for both the deployed and war reserve systems.

All deployed systems are operated at peacetime yearly usage rates.[10] At the end of a system's defined economic life, it is removed from the inventory. Where applicable it is assumed that a deployed system's detector/Dewar[11] unit is outgassed or gettered annually and that a combat consumption unit is gettered prior to deployment to offset the attrition of fielded systems. These gettered units undergo a routine performance check. Such special considerations may be deleted if not pertinent.

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10. This does not mean to imply any limits on the use rates which can be applied. War time usage presents special circumstances not necessarily considered in the model.
11. A component of a far infrared night vision viewing system.

In this model, costs are calculated in constant year dollars, current year dollars, and present value dollars. Current year dollars are obtained by use of the most recent DARCOM inflation (escalation) tables. Present value dollars are obtained by use of the standard DoD 10 percent discount after escalation.[12]

2.3 BASIC INPUT PARAMETERS, SCHEDULES, AND CONSTANTS

2.3.1 Variable Parameters

2.3.1.1 Module Parameters

The basic approach used in the model is the calculation of life cycle costs at a modular or subassembly level. A listing of the system's modules serves as the basic model input. The following data are required for each identified module:

Module J	Fiscal Year I
Basic average unit production cost	AUCM(J)
Basic buy quantity/first unit in buy	M(J)/M1(J)
Variable learning curve percentage applicable to module production	LC(I, J)
Mean time to repair at depot	MTTR(J)
Mean time between failures or mean time to failure	MTBF(J) or MTTF(J)
Module inherent weight	WT(J)
Depot material parts factor expressed as a percentage of module production costs	%(J)
Total module procurement quantity per fiscal year(I)	NMP(I, J)
Number of modules (J) in system	NMS

2.3.1.2 Operational Parameters

A second set of input data is used to define the system operational concept. These are as follows:

Yearly deployment system hours of operation	HOP or HOP(I)[13]
Mean time to repair system in field	MTTRF

---

12. AR 11-28.
13. HOP may be a constant or a variable function of the mix of systems being considered in the year I.

Number of nonstandard line items new to the Army logistic system	NSMP
Mean time to getter detector/Dewar module	MTTG
System economic life	E
Maintenance training course cost	CC
Replacement training rate	RTR
System maintenance float factor	SMFF
System commonality factor	SUF
Battery use factor	BUF
Deployment fraction	DEPER

2.3.1.3 System Schedules

The system has five associated schedules as input data. These schedules are:

Fiscal Year	No. of Systems Procured	No. of Systems Delivered	No. of Systems Overhauled	Competition Factor
I	NSP(I)	NSDEL(I)	NSO(I)	C(I)

2.3.2 Program Constants

The life cycle cost model contains a set of internal constants which are used in the calculation of the various life cycle costs. These constants[14] are:

Field maintenance labor rate (SAL3)[15]	$ 8.30
Depot maintenance labor rate (SAL2)[16]	$21.21
Depot turnaround time (TURNAR)[17]	1.5 months
Air cargo shipping rate[17]	$ 0.000216/lb-mi
Truck shipping rate[17]	$ 0.000178/lb-mi
Provisioning[17]	15% first production year 10% second production year 5% each additional production year
Nonstandard line item support factors[15]	$583 first production year $277 each additional production year
Yearly cost of a program manager (SAL1)[18]	$65,000

14. All monetary constants are in FY 78 constant dollars.
15. ECOMP 11-4, Volume 7, p V-9, VI-3, and VI-10.
16. U.S. Army Depot, Sacramento.
17. ECOM Maintenance Directorate.
18. ECOM Comptroller.

2.4 PROGRAM ALGORITHMS

2.4.1 Deployment

The number of systems deployed in fiscal year I is equal to the number of systems delivered in that year times the deployment fraction, plus the number deployed in the previous fiscal year (I-1).

$$NSD(I) = NSD(I-1) + DEPER \cdot NSDEL(I)$$

for $1 \leq I \leq E$ (1 refers to the first year of deployment)

When $I > E$

$$NSD(I) = NSD(I-1) - DEPER \cdot NSDEL(I-E)$$

All systems not deployed are stored at depot, thus:

$$NST(I) = NST(I-1) - 0.01 \cdot NSD(I-1) + (1 - DEPER) \cdot NSDEL(I)$$

for $1 \leq I \leq E$.

When $I > E$

$$NST(I) = NST(I-1) - 0.01 \cdot NSD(I-1) - (1-DEPER) \cdot NSDEL(I-E) \cdot (0.99)^{E-1}$$

This equation takes into account field attrition, which is compensated by debiting the depot storage quantity of systems. This allows the deployment level to remain constant while the storage level slowly diminishes at the field attrition rate. Depot replacement is not assumed a priori in this model. These algorithms also take into account the removal from inventory of all systems which have reached the end of their defined economic life.

2.4.2 Gettering

The number of systems to be gettered in fiscal year I is equal to the number deployed in the previous fiscal year (I-1) less those systems lost due to attrition:

$$NSG(I) = NSD(I-1) \cdot (.99)$$

for $1 \leq I \leq E$.

When $I > E$

$$NSG(I) = NSD(I-1) \cdot (.99) - DEPER \cdot NSDEL(I-E) \cdot (.99)$$

This equation takes into account the removal from inventory of previously deployed systems that have reached the end of their economic life.

2.4.3 Transportation

The life cycle cost model incorporates five transportation rates defined as follows (in units of dollars per pound):

RPDS - Rate for shipment from manufacturing plant to DS/GS location.[19]

RPD - Rate for shipment from manufacturing plant to system depot.

RDSB - Rate for shipment from DS/GS location to base or organizational level.

RDSD - Rate for shipment from DS/GS location to system depot.

RDPDP - Rate for shipment from system depot to vehicle (or other system) depot.

Transportation rates are calculated as follows:

Let:

X_i be the distance in miles from the manufacturing plant to the i^{th} DS/GS center,

y_i be the distance in miles from the system depot to the i^{th} DS/GS center,

z_{ij} be the distance in miles from the i^{th} DS/GS center to the j^{th} organizational level,

S_i be the number of systems consigned to the i^{th} DS/GS center,

S_{ij} be the number of systems consigned from the i^{th} DS/GS center to the j^{th} organizational level,

X_{pd} be the distance in miles from the manufacturing plant to the system depot,

X_{dpdp} be the distance in miles from the system depot to the vehicle (or other system) depot.

---

19. Approximation assuming co-location of DS and GS.

Then,

$$RPDS = 0.000216 \frac{\sum_i x_i S_i}{\sum_i S_i}$$

$$RPD = 0.000216 X_{pd}$$

$$RDSB = 0.000178 \frac{\sum_i \sum_j z_{ij} S_{ij}}{\sum_i \sum_j S_{ij}}$$

$$RDSD = 0.000216 \frac{\sum_i Y_i S_i}{\sum_i S_i}$$

$$RDPDP = 0.000216 X_{dpdp}$$

2.5 MODEL EQUATIONS

2.5.1 Investment Cost (OPA)

2.5.1.1 Modular Maintenance Float Factor

This factor determines the number of modular maintenance float modules that are needed initially to stock the DS/GS center. It also represents the percentage of system modules that will fail in a depot turnaround time (TURNAR), assuming a random failure rate.

$$MFF(J) = \frac{HOP}{MTBF(J)} \cdot TURNAR$$

2.5.1.2 Number of Modular Maintenance Float Modules to be Procured

The number of modular maintenance float modules of type J to be procured in fiscal year I is obtained by multiplying the modular maintenance float factor for module J by the procurement quantity for that module in fiscal year I

$$NMMF(I, J) = MFF(J) \cdot NMP(I, J)$$

2.5.1.3 Number of System Maintenance Float Modules to be Procured

The number of system maintenance float modules of type J to be procured in fiscal year I is obtained by multiplying the system maintenance float factor by the module procurement quantity in fiscal year I. These modules are assembled as systems, which become an initial supply of system maintenance float units.

$$NSMF(I, J) = (SMFF) \cdot NMP(I)$$

2.5.1.4 Number of Replacement Modules To Be Produced

The number of replacements, due to module wearout in fielded systems, of module type J to be procured in fiscal year I, is obtained as follows: The yearly failure rate HOP/MTTF(J) is multiplied by the number of systems deployed in fiscal year I.

$$NREPL(I, J) = \frac{HOP}{MTTF(J)} \cdot NSD(I)$$

2.5.1.5 Total Number of Modules to be Procured

$$NMP^T(I, J) = NMP(I, J) + NMMF(I, J) + NSMF(I, J) + NREPL(I, J)$$

2.5.1.6 Learning Curve Exponent

The learning curve exponent for the module of type J in fiscal year I is obtained by taking the common logarithm of the learning curve percentage expressed as a fraction and dividing by the common logarithm of 2. This result is derived from learning curve theory.[20]

$$B(I, J) = \frac{LOG\ [0.01 \cdot LC\ (I, J)]}{LOG\ 2}$$

---

20. Sirota, D., Learning Curve Theory, NVL Report, Dec 1975.

2.5.1.7 First Unit Production Cost

The first unit production cost is obtained by dividing the product of the basic average unit production cost and basic buy quantity by the cumulative total of the basic buy quantity lot. This result is derived from learning curve theory.

$$FUC(J) = \frac{M(J) \cdot AUCM(J)}{\displaystyle\sum_{M1(J)}^{M1(J) + M(J)} N^{B(J)}}$$

2.5.1.8 Average Unit Production Cost

The average unit production cost of module J in fiscal year I is obtained by multiplying the first unit cost of module J by the cumulative total for the module J production lot in fiscal year I and by the competition factor. The result is divided by the lot quantity. The equation is derived from learning curve theory.

$$AUC(I, J) = \frac{FUC(J)}{NMP^T(I,J)} \cdot \sum_{NMP^T(I-1,J)+1}^{NMP^T(I,J)+NMP^T(I-1,J)} N^{B(I,J)} \cdot C(I,J)$$

2.5.1.9 Hardware Cost

The system average unit production cost is obtained by summing the module average unit production cost (AUC(I, J)) over all modules. The hardware cost in fiscal year I is then obtained by multiplying the system average unit production cost by the number of systems to be procured.

$$HARDC(I) = \sum_J AUC(I, J) \cdot NSP(I)$$

2.5.1.10 Provisioning Cost

The provisioning cost is the cost of an initial supply of repair parts and special tools to stock the depot. Calculation of provisioning cost as a percentage of the hardware cost is in accordance with the ECOM cost manual.

$$ISPC(I) = ISP \cdot HARDC(I)$$

where
$$ISP = 0.15 \text{ if } I = 1$$
$$= 0.10 \text{ if } I = 2$$
$$= 0.05 \text{ if } I > 2$$

2.5.1.11 Maintenance Float Cost

The maintenance float cost is the sum of the cost of the modular maintenance float modules required specifically for the system and the cost of the system maintenance float units.

$$MFC(I) = \sum_J AUC(I, J) \cdot [MFF(J) \cdot NSP(I) + NSMF(I, J)]$$

2.5.1.12 Module Shipping Weight

The module shipping weight is related to the module inherent weight by the following estimating relationship derived from historical weight data for night vision systems.

$$MSWT(J) = [3.202424 + 0.00532\ WT(J)] \cdot WT(J)$$

2.5.1.13 System Shipping Weight

The system shipping weight is related to the system inherent weight by the same cost estimating relationship used to determine module shipping weight.

$$SSWT = \sum_J WT(J)\ [3.202424 + 0.000532 \sum_J WT(J)]$$

The shipping equations hold for values in the approximate range

$$2.79 \text{ lbs} \leq SSWT \leq 187 \text{ lbs and}$$

$$0.72 \leq \sum_J WT(J) \leq 50 \text{ lbs.}$$ [21]

2.5.1.14 Initial Transportation Cost

The initial transportation cost equation consists of three terms. The first term represents the cost of shipping the deployed systems, the associated system maintenance float units, and the associated modular maintenance

21. For values of SSWT and $\sum_J WT(J)$ beyond those indicated, adjustments may be necessary to the equation constants. Actual weights may be used of course with appropriate adjustment of the constants.

float modules from the plant to the DS/GS location. The second term represents the cost of shipping the systems from the DS/GS location to the base location. The third term represents the cost of shipping the stored systems, the associated system maintenance float units, and the associated modular maintenance float units from the manufacturing plant to the Army depot.

$$\begin{aligned} \mathrm{ITRC(I)} = {} & \mathrm{RPDS} \cdot \mathrm{DEPER} \cdot \mathrm{NSP(I)} \cdot [\mathrm{SSWT(1{+}SMFF)} + \sum_{J} (\mathrm{MFF(J)} \cdot \mathrm{MSWT(J)}] \\ & + \mathrm{RDSB} \cdot \mathrm{DEPER} \cdot \mathrm{SSWT} + \mathrm{RPD} \cdot \mathrm{(1{-}DEPER)} \\ & \cdot \mathrm{NSP(I)} \cdot [\mathrm{SSWT(1{+}SMFF)} + \sum_{J} (\mathrm{MFF(J)} \cdot \mathrm{MSWT(J))}] \end{aligned}$$

2.5.1.15 Initial Maintenance Training Cost

The initial maintenance training cost represents the cost of training all maintenance personnel who may be involved in the maintenance of the system at the DS/GS location. System commonality is assumed here and cost is allocated to the various systems in accordance with the system commonality factor SUF.

$$\mathrm{ITC(I{-}1)} = \mathrm{CC} \cdot \mathrm{NOMM} \cdot \mathrm{SUF}$$

2.5.1.16 Contractor Engineering Cost

Contractor engineering cost ENGCON(I) is defined as engineering cost incurred by the contractor to evaluate engineering change proposals (ECP's). It is an engineering cost over and above the production engineering normally associated with production hardware costs.

2.5.1.17 Proof and Testing Services Cost

Proof and testing services cost PTSUS(I) is that incurred by the contractor in carrying out destructive or potentially destructive tests of production systems.

2.5.1.18 Proof and Testing Components Cost

Proof and testing components cost PTCOMP(I) is the cost of production systems procured specifically for destructive or potentially destructive testing.

$$PTCOMP(I) = 80.01 \cdot NSP(I)$$ [22]

2.5.1.19 Recurring Tooling Cost

Recurring tooling RETOOL(I) is the cost of replacing wornout tooling during the production process.

$$RETOOL(I) = 72.68 \cdot NSP(I)$$ [23]

2.5.1.20 Total Investment Cost

Total investment cost (PEMA) includes a number of costs in addition to those discussed.[24] They are listed below the equation.

$$\begin{aligned} IC(I) = {} & HARDC(I) + ISPC(I) + MFC(I) + ITRC(I) + ITC(I) \\ & + RETOOL(I) + ENGCON(I) + PTSUS(I) + PTCOMP(I) \\ & + TSMC(I) + INTC(I) + DC(I) + IPFC(I) + QAC(I) \\ & + ENGC(I) + ECOC(I) + DTIIIC(I) \end{aligned}$$

TSMC(I) is the total systems management cost. This cost is due to the procurement and administrative effort involved in the investment phase of the system's life cycle.

INTC(I) is the instructor training cost for a training course given at the contractor's plant that deals with the operation and maintenance of the system.

DC(I) is the documentation cost. This cost is associated with all data procured as part of the production contract.

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22. Factor derived from historical data on DRAGON Tracker (M47).
23. Ibid.
24. These cost centers may be zeroed out as required for a particular analysis or additional centers added as required.

IPFC(I) is the initial production facilities cost. This cost is for the construction of buildings and the fabrication of tooling required for the production of the system.

QAC(I) is the quality assurance cost. This cost is for effort required to insure that the produced system meets specifications. This element is included in ENGC(I) below.

ENGC(I) is the Government engineering cost. This cost is associated with in-house design effort undertaken during the production phase to improve the system and includes quality assurance costs [QAC(I)].

ECOC(I) is the engineering change order cost. This cost is associated with the administrative effort for production engineering. (Alternative: may be an anticipatory set aside for hardware changes due to implementation of ECP's.)

DTIIIC(I) is the production testing cost. This cost is associated with the testing of initial production units.

2.5.2 Operations and Support Cost (OMA)

2.5.2.1 Replacement Training Cost

The replacement training cost accounts for the training of additional maintenance personnel to replace personnel, initially trained, who leave the service. The cost is computed by multiplying the initial maintenance training cost by an average yearly replacement rate (RTR). System commonality is taken into account and costs are allocated to the various systems by the system commonality factor SUF.

$$RTC(I) = RTR \cdot CC \cdot NOMM \cdot SUF$$

for all deployment years.

2.5.2.2 Field Labor Cost

Field labor cost is due to labor costs of system repair and of field gettering where appropriate.

$$FLC(I) = RLC(I) + FGLC(I)$$

2.5.2.2.1 System Repair Labor Cost

This cost is due to the troubleshooting of the defective system at the DS/GS location and replacement of the defective module. HOP/MTBFS represents the expected number of yearly failures of each deployed system.[25]

$$RLC(I) = \frac{HOP \cdot MTTRF \cdot SAL3 \cdot NSD(I)}{MTBFS}$$

where $MTBFS = \left(\sum_{J} \frac{1}{MTBF(J)} \right)^{-1}$

2.5.2.2.2 Field Gettering Labor Cost

In those cases where field gettering is performed on each deployed system each year, the field gettering labor cost is the product of the mean time to getter, field maintenance labor rate, and number of systems to be gettered.

$$FGLC(I) = MTTG \cdot SAL3 \cdot NSG(I)$$

2.5.2.3 Nonstandard Line Items Logistics Support Cost (ILS)

$$ILSC(I) = ILSF(I) \cdot NSMP \cdot SUF$$

where $ILSF = \$583$ if $I = 1$

$ILSF = \$277$ if $I \neq 1$

This cost is due to introduction and maintenance of nonstandard line items associated with systems that are new to the Army logistics system. Costs were obtained from the ECOM Cost Manual. System commonality is taken into account and costs are allocated in accordance with the system commonality factor SUF.

2.5.2.4 Depot Maintenance Cost

Depot material parts costs and depot labor costs have been included.

$$DMC(I) = DMPC(I) + DLC(I)$$

2.5.2.4.1 Depot Material Parts Cost

Depot material parts cost refers to the cost of the piece parts used to repair failed repairable modules at the depot. The depot material parts

25. HOP(I) may be used.

factor expressed as a percentage of module production cost %(J) is a function of both the production cost and the mean time between failures of the piece parts that constitute a repairable module.

$$DMPC(I) = \sum_{J} \frac{HOP \cdot \%(J) \cdot AUC(I,J) \cdot NSD(I)}{MTBF(J) \cdot 100} \quad [26]$$

where

$$\%(J) = \sum_{i=1}^{N} \frac{\frac{(PC)_i}{(MTBF)_i}}{\frac{MC(M)}{MTBF(M)}}$$

$(PC)_i$ = Cost of the i^{th} piece part needed to repair the Module (M)

$(MTBF)_i$ = The MTBF associated with the i^{th} piece part

MC(M) = The replacement cost of the Module (M) without repair

MTBF(M) = The MTBF of the Module (M)

N = The number of piece parts associated with the Module (M) ·

Where detailed data are not available, estimates may be made against the above definition by analogy to other systems for which sufficient data is available.

2.5.2.4.2 Depot Labor Costs

Depot labor cost refers to the labor cost associated with the repair of failed modules at the depot.

$$DLC(I) = \sum_{J} \frac{HOP \cdot MTTR(J) \cdot SAL2 \cdot NSD(I)}{MTBF(J)} \quad [27]$$

2.5.2.5 Depot Inventory Holding Cost

Depot inventory holding cost comprises system and modular storage cost and cost of gettering systems that are taken from storage for use in the field, to offset field attrition.

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26. HOP(I) may be used.
27. Ibid.

2.5.2.5.1 Modular Holding Cost

$$MHC(I) = NST(I) \cdot MHF \cdot \sum_{J} AUCM(I,J) \cdot (MFF(J) + SMFF) \cdot NMS(J)$$

2.5.2.5.2 System Holding Cost

$$SHC(I) = NST(I) \cdot SHF \cdot AUCS(I)$$

where

NST(I) = Number of systems stored in fiscal year I

MHF = Module holding factor (default value = 0.03)[28]

SHF = System holding factor (default value = 0.01)[28]

MFF(J) = Module maintenance float factor

NMS(J) = Number of modules (J) procured or required for use with each system

$$AUCS(I) = \sum_{J} AUC(I, J)$$

2.5.2.5.3 Depot Gettering Labor

For all systems in which gettering is required, all stored systems (detector/Dewars) are forcibly outgassed (gettered) before deploying to replace field attrition. Depot gettering labor is given by

$$DEGETLAB(I) = MTFG \cdot SAL2 \cdot NG(I)$$

where

MTFG = Mean time for gettering

NG(I) = Number of systems to be gettered

SAL2 = Depot labor rate

2.5.2.6 Transportation Cost

Depot maintenance transportation cost and transportation cost of systems for gettering have been included.

$$TRC(I) = TRDRC(I) + TRGC(I)$$

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28. ECOMP 11-4, Vol 7, VI-12.

2.5.2.6.1 Depot Maintenance Transportation Cost

The first term is the cost of shipping the system from the Organization level to the DS/GS location and shipping a system maintenance float unit from DS/GS to the Organization level. The second term is the cost of shipping the defective repairable modules to and from the depot for repair.

$$TRDRC(I) = \frac{2\ RDSB \cdot HOP \cdot SSWT \cdot NSD(I)}{MTBFS} + \sum_J \frac{2 \cdot RDSD \cdot HOP \cdot MSWT(J) \cdot NSD(I)}{MTBF(J)}$$ [29]

2.5.2.6.2 Transportation of Systems for Gettering

$$TRGC(I) = 2 \cdot RDSB \cdot NSG(I) \cdot SSWT$$

The factor NSG(I) represents the number of deployed systems to be gettered at DS/GS in fiscal year I.

2.5.2.7 Depot Overhaul Cost

The first term represents the actual depot overhaul cost. The cost estimating relationship employed was obtained from the ECOM Manual.[30] The second term represents the transportation cost for depot overhaul. It is the cost of transporting the system from the base to the appropriate system depot and return.

$$DOC(I) = 0.809\ \left[\sum_J AUC(I,\ J)\right]^{0.881} \cdot NSO(I) + 2(RDSD + RDSB) \cdot SSWT \cdot NSO(I)$$

2.5.2.8 Consumables

Four consumables are recognized and estimated by program algorithm. These are valves, cartridges, batteries, and other. They are calculated as follows:

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29. HOP(I) may be used.
30. ECOMP 11-4, Volume 7, p VI-14.

$$\text{CONSUM (SYS, I)} = \text{HOP} \cdot \text{NSD(I)} \cdot \frac{\text{AUC(I, J)} + (\text{RDSB} + \text{RDSD}) \cdot \text{MSWT(J)}}{\text{MTTF(J)}}$$ [31]

2.5.2.9 Total Operations and Support Cost (OMA)

$$\text{OC(I)} = \text{RTC(I)} + \text{FLC(I)} + \text{ILSC(I)} + \text{DMC(I)} + \text{MHC(I)} + \text{SHC(I)} + \text{DETGETLAB(I)} + \text{TRC(I)} + \text{DOC(I)} + \text{CONSUM(I)}$$

2.5.3 Total Life Cycle Cost

Total LCC is obtained by summing the costs of research and development, investment, and operation. RD(I) is the research and development cost in fiscal year I. The research and development cost is categorized as either sunk or future costs. Sunk research and development costs are added as a single constant and are not inflated.

$$\text{LCC} = \sum_{I} [\text{RD(I)} + \text{IC(I)} + \text{OC(I)}]$$

31. HOP(I) may be used.

3. SPECIAL CONSIDERATIONS AND METHODOLOGY

3.1 GENERAL

As stated in Section 2.2. the basic model is based on a modular or subassembly maintenance concept in which the operator noting a malfunction sends the failed system to the Direct Support/General Support (DS/GS) maintenance area. Here the failure is isolated to a particular module. The failed module is then replaced by a maintenance float unit and the system is then returned to the user or placed in the system maintenance float bin. The failed module is shipped to the depot for actual repair. There will be, and are, systems for which this concept is not completely suitable and for that reason Sections 3.2 and 3.3 will describe two modifications which have been used in the Night Vision area. Section 3.4 will discuss utilization of the model when the "system" is simply a module but one which is common to a half dozen or more systems all with differing procurement plans, operational use rates, etc.

3.2 TANK THERMAL SIGHT, TTS (AN/VSG-2) APPLICATION PROBLEM DESCRIPTION

3.2.1 The TTS consists of four subassemblies or black boxes. These subassemblies each contain a set of replaceable modules. These subassemblies are:

1. Head Assembly containing optical elements that facilitate day/night surveillance of the area adjacent to the tank and sensor modules that convert incoming far infrared radiation into a visible display. It allows for daytime viewing of the surrounding area by the tank gunner.

2. Commander's Display which facilitates nighttime viewing by the tank Commander.

3. Gunner's Display which facilitates nighttime viewing by the gunner.

4. Power Converter which conditions and distributes electrical power generated by the tank to the various TTS subassemblies.[32]

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32. Sirota, D., Life Cycle Cost Analysis, Tank Thermal Night Sight AN/VSG-2( ), NVL Rept., Jul 1976.

3.2.2 Analytical Approach

This system must be treated in essence as four systems instead of one. This model is accordingly based on an organizational subassembly maintenance concept. Organizational maintenance consists of troubleshooting the failed TTS system while still installed in the tank in order to isolate the defective subassembly. The defective subassembly is replaced at this point.

Field maintenance consists of troubleshooting the failed subassembly to isolate and replace defective modules. This is done at the DS/GS location. As in the basic application of the model, modules are then shipped to depot for repair.

It is tempting at times to break systems up into subassemblies for analysis but the key to the feasibility of doing this in the LCC model is simply: if the system as a whole must be sent to DS/GS for fault isolation of modules then it cannot be treated as a collection of subassemblies; if however, identifiable subassemblies do in fact move independently to DS/GS then the subassembly approach is appropriate.

In the basic application of the model there is one system labeled PRIME and in addition there may be several supporting or ANCILLARY systems. The PRIME and ANCILLARIES move independently through the maintenance cycle according to their respective failure rates and operational use rates, i.e., HOP/MTBF ratios. In the TTS application of the model there are four PRIME systems and the possibility of ANCILLARIES. Here the PRIMES move independently through the maintenance cycle as do the ANCILLARIES. This approach, where appropriate, can be used without change to the model equations or algorithms. In other cases changes must be made in the equations themselves. Changes such as these have not been added to the computer program but rather are added manually as input data in an iterative process. Permanent inclusion in the program

itself would occur if repeated analysis of the latter type were required. An example of this type of manual adaptation follows in Section 3.3.

3.3 REMOTE PILOTED VEHICLE RPV APPLICATION[33]

3.3.1 Problem Description

The RPV Vehicle is a remotely piloted aircraft designed for battlefield surveillance. It would include a night vision system mounted in a special turret assembly which also contains gimbals and mounts, boresighting equipment and a laser rangefinder designator. This system can only be boresighted at depot due to the sensitivity of adjustments and the degree of cleanliness required. For this reason if a modular failure occurs within the boresight train (i.e. any failure which impairs boresight alignment) then the entire turret assembly moves from organization to DS/GS and on to depot. If however a modular failure occurs which is independent of the boresighting train then the turret assembly simply moves between organization and DS/GS and only the failed module moves on to the depot for repair. Clearly the basic application of the model does not permit this type of occurrence. Section 3.3.2 shows a possible analytical approach to this problem.

3.3.2 Analytical Approach

There are two changes which must be made to the LCC model in order to properly reflect the maintenance concept currently envisioned for the RPV FLIR system. These are the inclusion of depot boresighting labor DEPBORLAB(I) and an adjustment in the transportation equation to account for DEPBORLAB(I). As stated above the basic model assumes round trip system shipment from the field to DS/GS and return and round trip module shipment from DS/GS to depot. The RPV FLIR systems require that the system undergo a round trip for every

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33. Morrow, W.B., Life Cycle Cost Analysis of Proposed Day/Night FLIR System Alternatives for Remote Piloted Vehicle (RPV), NV&EOL Rept., 19 Jul 1978.

failure that perturbs boresight alignment. In addition modules undergo round trip shipment to depot if they are not in the boresight train of the system.

3.3.2.1 Depot Boresighting Labor, DEPBORLAB(I)

Depot boresighting labor is given by:

$$DEPBORLAB(I) = \frac{HOP \cdot MTTBS \cdot SAL2}{MTBFB} \cdot NSD(I)$$

where:

MTTBS = Mean time to boresight the system in hours.

MTBFB = Mean time between failure of the set of modules constituting the boresight train of the system. It may include the turret assembly objective optics, scanner, detector/Dewar, IR imager, etc. It does not, in general, include scan converter/multiplexing modules, video electronics or camera tubes. It is a variable from system to system.

3.3.2.2 Transportation Correction

Under the basic LCC model, maintenance transportation costs are given by the relation

(a) $TRC(I) = TRDRC(I) + TRGC(I)$

where

(b) $$TRDRC(I) = \frac{2\ RDSB \cdot HOP \cdot SSWT(J) \cdot NSD(I)}{MTBFS} + \sum_{J} \frac{2\ RDSD \cdot HOP \cdot MSWT(J) \cdot NSD(I)}{MTBF(J)}$$

(c) $TRGC(I) = 2\ RDSB \cdot NSG(I) \cdot SSWT$

and

(d) $NSG(I) = NSD(I-1)(.99)$.

The parameters and variables are as previously defined in Section 2, Basic Mathematical Model-General Methodology.

Recall also that

(e) $MSWT(J) = [3.202424 + 0.000532\ WT(J)]\ WT(J)$

and

(f) $SSWT = \sum_J WT(J)\ [3.202424 + 0.000532 \sum_J WT(J)]$

For the RPV-FLIR system it is the second term of equation (b) that needs to be modified to include depot shipment for boresight train failure. This is done by expanding the second term as follows:

$$\text{(g)}\quad TRDRC(I)^* = \frac{2\ RDSB \cdot HOP \cdot SSWT \cdot NSD(I)}{MTBFS} + \frac{2\ RDSD \cdot HOP \cdot SSWT}{MTBFB} \cdot NSD(I) + \sum_K \frac{2\ RDSD \cdot HOP \cdot MSWT(K)}{MTBF(K)} \cdot NSD(I)$$

where

$$\text{(h)}\quad MTBFB = \left[\sum_J \frac{1}{MTBF(J)}\right]^{-1}$$

The first J modules impact boresight when they fail and dictate system shipment to depot while the remaining K modules do not impact boresight and dictate module shipment to depot.

We now have

(i) $TRC(I)^* = TRDRC(I)^* + TRGC(I)$

In this analysis TRC was first calculated by the computer and a ΔTRC added, i.e. $TRC(I)^* = TRC + \Delta TRC$.

$$\text{(j)}\quad \Delta TRC = \left[\frac{TRC^*}{TRC} - 1\right] TRC$$

The ratio TRC*/TRC can be written in the form

$$\text{(k)}\quad K(I) = \frac{TRC(I)^*}{TRC(I)} = \frac{A\ \frac{NSD(I)}{NSD(I-1)} + 1}{B\ \frac{NSD(I)}{NSD(I-1)} + 1}$$

for all I > 1. If I = 1 we define

$$\frac{NSD(I)}{NSD(I-1)} = 1$$

A and B are system dependent constants. We may then write:

(l) $\Delta TRC(I) = [K(I) - 1]\ TRC(I)$

In the case of systems for which no gettering is required the second term of equation (a) is zero, i.e.

(m) $TRGC(I) = 0$

This reduced to

$$TRC(I) = TRDRC(I)$$

and

$$TRC(I)^* = TRDRC(I)^*$$

Moreover

$$K(I) = \frac{TRC(I)^*}{TRC(I)} = \frac{TRDRC(I)^*}{TRDRC(I)} = \frac{M\ NSD(I)}{N\ NSD(I)}$$

$\frac{M}{N}$ = a constant independent of the fiscal year I

We have now:

$$K = \frac{M}{N}$$

where M and N are system dependent constants and

$$\Delta TRC(I) = (K - 1)\ TRC(I)$$

3.3.3 Comments

In general the model is first exercised in its basic form; then by utilization of a routine in the computer program which allows addition or subtraction of arbitrary values from specific parameters, the values of $\Delta TRC(I)$ are included. In addition a new parameter line for DEPBORLAB(I) is entered with the computed values. With these two entries the computer model is exercised a second time to complete the analysis.

3.4 LIGHT EMITTING DIODE ARRAY (LED) PRODUCT IMPROVEMENT APPLICATION[34]

3.4.1 Problem Description

In this analysis the problem is to deal with a system but with a component module common to several systems having differing use rates. Moreover the problem includes changing the module by product improvement for some systems but not others. What is wanted is a determination of the cost effectiveness of the product improvement.

The present configuration of the Common Module Light Emitting Diode (LED) uses a 180-element array regardless of the number of channels in the Night Vision System utilizing the LED. A product improvement of this LED is being investigated whereby the Manportable family of Night Vision Systems (TOW, DRAGON, NODLR, and GLLD) will use an LED having a 60-element array. Because of fewer elements, it is hypothesized that the basic cost of the LED should be considerably lower than that of the present LED.

There are three sets of systems using the Common Module LED. The Manportable family of systems currently plans production of about 15,000 systems from a prime contractor and about 2,500 from a second source. The Tank Thermal Sight (TTS) plans about 3,500 systems assumed to be made by a prime, and the Advanced Attack Helicopter (AAH) will have about 1,000 systems assumed to be made by a second source.[35] The Manportable systems currently use 60 elements of the present 180-element LED and will use the 60-element LED when it becomes available. The AAH systems will use all 180 elements, and the TTS has 120 channels and thus must always use 180-element LED's.

The table below shows the typical input data which might be used in each program. Different baseline AUC's were used for each program because of such things as effects of competition as shown by bids, and different methods used

34. Swenson, J. M., Light Emitting Diode Product Improvement Economic Analysis, NV&EOL Rept., Oct 1978.
35. Quantities are arbitrary for illustrative purposes only.

by different analysts to determine baseline costs. This analysis compares only the effect of reduced costs of a 60-element LED upon existing estimates of program cost, so all other inputs were kept the same as when validated.

LED INPUT DATA

	Man-Port Prime		Second Source			
	180 elem	60 elem	180 elem	60 elem	TTS	AAH
Baseline AUC[36]	$1,300	$780	$750	$500	$2,000	$6,000
Baseline LOT	#1-1941	#1-1941	#1-30000	#1-30000	#1-300	#1-44
Learning Curve #1	0.865	0.865	0.90	0.90	0.85	0.89
L.C. #1 End Point	1942	1942	N/A	N/A	N/A	N/A
Learning Curve #2	0.850	0.850	N/A	N/A	N/A	N/A
MTBF (hrs)	11,715	11,715	11,715	11,715	5,858	3,905
MTTR (hrs)	0.53	0.53	0.53	0.53	0.53	0.53
Weight (lbs)	0.43	0.43	0.43	0.43	0.43	0.43
Repair Part Factor	0.173	0.250	0.173	0.250	0.173	0.173
Oper Hrs/Year (HOP(I))	Variable between 137 and 202 based upon 4 system mix				480	248.5
Economic Life (yrs)	15	15	15	15	15	15

To indicate the range of savings possible, the NV&EOL Life cycle cost model was used to obtain the life cycle cost associated with the LED module for three cases: (1) all programs using the present configuration of 180-element LED's for their entire economic life; (2) the Manportable program changing to the 60-element LED starting in FY80 with complete independence between the two types; and (3) same as (2) except with complete production line commonality between the two types.

36. Numbers are arbitrary and do not represent actual quotes or contract prices.

3.4.2 Analytical Approach

While this problem appears to be quite complex on the surface it is easily resolved using the LCC model in the same fashion as was done for the TTS (Section 3.2). In this case there is no ANCILLARY equipment but there are up to six (6) PRIME systems, i.e.

(1)	Manportable Prime Source	180 element
(2)	Manportable Prime Source	60 element
(3)	Manportable Second Source	180 element
(4)	Manportable Second Source	60 element
(5)	TTS (One Source)	180 element[37]
(6)	AAH (One Source)	180 element

Each system runs independently as a PRIME subsystem but with production commonality taken into account where necessary or desirable. The output when using the computer model shows the results for each subsystem as well as the combined results. Nowhere in this analysis was it necessary to get involved with the Night Vision systems in which the LED modules are used except to recognize their differing use rates and MTBF's as dictated by environmental factors. Moreover, actual costs for each contract could be used to good advantage.

37. Only 120 elements are used. Also more than one source here would not be a problem to handle.

4. INPUT DATA REQUIREMENTS

4.1 GENERAL

As with any cost, economic, or systems analysis a close working relationship between the analyst and cognizant project engineers is critical to the deliverance of a good product. To the analyst familiar with the model, the type and quality of data needed is usually self evident, but it needs to be communicated to those from whom the data must be obtained. With this in mind the following list of items is suggested as an approach to obtaining the data necessary to exercise this model.

4.2 INITIAL DATA REQUIREMENTS

4.2.1 Data List

a. A comparative engineering description of the proposed system and ancillary equipments. The comparison should be detailed and should reflect any and all differences between the proposed system and existing systems which are similar and for which a cost data base has been established.

b. Procurement plan including number and identification (if possible) of sources from whom systems will be procured, i.e., value of anticipated competition.

c. Procurement and delivery schedule by year and source.

d. Expected system and component module operational life expressed as MTTF's and/or MTBF's with end of life performance defined as required.

e. Any existing cost history for this system and/or similar systems.

f. Projected R&D requirements.

g. Physical weights for component modules, subassemblies, etc.

h. Training (operator and maintenance) anticipated - type, duration, and time frames.

i. Are there any phase-in phase-out relationships with other systems or systems being replaced, product improvements or major component substitutions anticipated.

j. Economic life of the proposed system considering operational life, obsolescence, and probability of threat cancellation. When is this system likely to be replaced?

k. Peacetime operational use rates of deployed systems in hours/year.

l. Percentage of systems being deployed vs percent held as combat consumption or war reserve units.

m. Maintenance Concept - Are systems, subsystems or components repairable or throwaway. What is the extent of field, DS/GS, and depot maintenance? What MOS rating(s) is to be used for maintenance?

n. Projected nonrecurring and recurring tooling and facilitization required by contractor.

o. Special requirements support or auxiliary equipment, ground or airborne vehicle interface requirements or constraints.

p. Budget constraints and schedule constraints, if any, by year.

q. Are maintenance floats implicit in the production quantities given or do they need to be computed in accordance with the model?

4.2.2 Comments

Detailed data derived from this list, though not exhaustive, forms a sound basis for exercising the model. Is it, however, all necessary? Clearly, some of it relates to investment cost and some to operations and support cost. For a life cycle analysis, all is necessary. Investment costs may be computed without regard to operations and support costs but at some sacrifice in accuracy as the two categories are not completely independent. They are often coupled by hardware costs and maintenance float requirements which are driven by the HOP/MTBF ratio.

Are there problems associated with using the model? While broadly applicable, there will be systems for which the model cannot be forced to work. The analyst must understand the model well enough to discern its limitations. Beyond this there are the universal problems associated with cost analysis. It is suggested that many "...are prepared in haste without due consideration of what the actual use of the data will be. Others are prepared with a lack of concern as to what will be implemented within the user community and others are just thrown together. It is imperative that the cost analyst discuss with the user a means by which they can utilize each other's data and fully understand the alternatives.---- Make sure that your estimates can be used safely---and that they are correct."[38]

If the analyst/user will keep these considerations in mind then the model will for the most part be limited only by the creativity and imagination of the user.

38. Lee, Robert E., Problems in Cost Estimating, ARRADCOM Rept. Jul 1978.

5. SENSITIVITY AND UNCERTAINTY

5.1 GENERAL

DoD and the Services have shown an increasing awareness that there is an uncertainty associated with Life Cycle Cost Estimates and the further that system costs are projected into the future, the greater is the uncertainty of those costs. Current systems acquisition policy documents (DoD 5000.1 and implementing instructions) emphasize the need for displaying and considering this uncertainty at decision making points. These documents do not, however, specify techniques to be used in the display and evaluation of cost uncertainty.

Sensitivity analyses are necessary to determine which cost parameters are dominant and which must be determined with the greatest accuracy. It is not unusual that a very few key parameters drive the bulk of the costs in any system. It is often stated that 20 percent of the cost centers account for 80 percent of the actual costs.

5.2 Uncertainty

In past exercises of the LCC model cost uncertainty has been dealt with in a somewhat subjective way by utilizing point estimates of uncertain parameters to obtain worst case, best case, and most likely estimates of life-cycle costs. The problem of uncertainty is left to the user to recognize and deal with according to the available understanding. No attempt thus far has been made to associate within the body of the mathematical model or computer program the capability of accepting probability distributions in lieu of point estimates of uncertain parameters. However, this is a strong consideration for future incorporation if at all feasible. In the mean time, the user might consider the approach developed by W. M. Lewis, Jr. at the Defense Systems Management School.[39]

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39. Lewis, Warfield M., Jr. A Simple Statistical Method of Presenting the Uncertainty Associated with Life Cycle Cost Estimates, Defense Systems Management School, Program Management Course, Class 73-1, Ft. Belvoir, VA 22060, May 1973.

5.3 Sensitivity

In its present configuration the computer model allows, with relative ease, the performance of sensitivity analyses on a number of parameters. These include learning curve percentages, basic average unit production costs, MTTF, MTBF, MTTR, module weight, depot material parts factors, operational use rates, field and depot labor rates, shipping rates, economic life, production and delivery schedules and others. Basically the model is exercised while varying a preselected parameter over a predetermined range while holding all other parameters constant. When using the computer model a complex sensitivity analysis sequentially varying parameters can be done with a single input to the computer.

6. EXERCISING THE MODEL

6.1 MANUAL PROCESSING

The model as described in this report can be implemented and exercised as a manual model but it rapidly becomes very cumbersome for complex systems and long economic lives. Sensitivity and uncertainty analyses are difficult in the manual mode. Time spent in rework and double checking can be significant. Computing system schedules when given budget constraints becomes very tedious in the manual mode for any but the simplest systems. For these reasons NV&EOL personnel have developed a relatively sophisticated computer program to multiply many times the model's usefulness.

6.2 Computer Processing

It is in the use of the computer model and program described in Part II and Part III of this report that is found the real power and capability of the model. It is suggested here that utilization of the computer model coupled with imaginative improvisation in the manual mode can provide the most varied capability. It is in this way that the model is most often used at NV&EOL. The computer model is presently written in FORTRAN for the CDC 6600 computer system and consideration has been given to the possibility of conversion to IBM FORTRAN should the need arise. Part II of this report will provide the user with a description of and detailed instructions for implementing the NV&EOL Life Cycle Cost Computer model. The computer program is given in detail in Part III.

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